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The load control strategy of datacenter

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Abstract

With development of information technology and growth for various types of cloud computing demand, many data centers have been deployed in cities, and their characteristics of high energy consumption, high peak-load are becoming increasingly prominent, which make a huge impact on urban grid. According to workload prediction in different time intervals, this paper proposes a simplified piecewise load control strategy of datacenter, which could reduce power consumption and peak-load by dynamically adjusting the number of working servers and CRACs. Finally, a simple example is used to validate the performance of our strategy.

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Keywords: Datacenter, State queue model, Workload prediction, Server consolidation, Temperature adjustment

1. Introduction

In recent years, datacenters consume large amounts of electricity for powering both their IT equipment and cooling infrastructure. To reduce the both energy consumption, many researches have made efforts in workload scheduling based on temperature sensing. In [1] the authors maximize the steady state datacenter cooling efficiency by maximizing the required supplied cold-air temperature value, but the maximum cooling efficiency does not necessarily result in minimum total datacenter power consumption. In [2] the authors dynamically provision the servers to meet the required workload while ensuring that a maximum temperature threshold is met throughout the datacenter, but they only concern the minimum power consumption without considering the peak-load shaving.

In this paper, according to the predicted workload in different time intervals, we propose a novel load control strategy to achieving the reduction of huge power consumption and peak-load of datacenter, and validate the performance of our control strategy.

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Nomenclature

CRAC	Computer room air conditioner
SQ	State queue
h	Servers' average utilization
P_{max}	Maximum power of a single server (kW)
$P(h)$	Power of a single server (kW)
M	Number of working servers
$P_{Servers}$	Total power of all working servers (kW)
T^t	Temperature of cold air duct at time t (℃)
$[T_-,T_+]$	High- and low-temperature setting of all CRACs (℃)
Δt	Simulated time step of CRACs (min)
δ	Temperature deadband of CRACs (℃)
α	On/off status of CRACs (on=1, off=0)
N	Number of CRACs at "on" states
P_N	Rated power of a single CRAC (kW)
P_{CRACs}	Total power of "on" CRACs (kW)
L_{DC}	Total power load of a datacenter (kW)
i	i-th CRAC
x	x-th time interval
k	k-th group of total intervals
j	j-th interval of a group

2. Load model construction

In this paper, we only consider total power of servers and CRACs. A modern datacenter is designed in hot-aisle/cold-aisle style as depicted in Figure.1, where green parts denote server cabinet, long blue arrows denote cool air and red arrows indicate hot air from cabinets. Cold air in cold aisles is supplied by the AC unit and comes through the perforated tiles in the floor. Cold air in cold aisles is supplied by the AC unit and comes through the perforated tiles in the floor. Servers suck the cold air coming from the cold aisle. The cold air cools the servers; the hot air enters into the adjacent hot aisles, and is then extracted from the room by the AC intakes on the ceiling above the hot aisles.

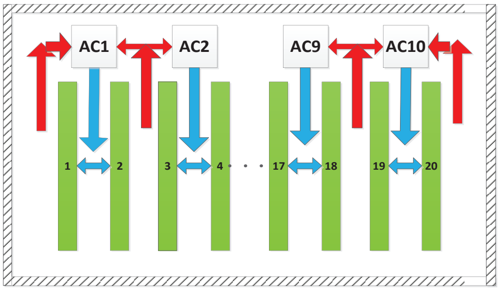

Figure.1. layout of a computer room

2.1. Servers power model

Assuming that all servers are the same type, *P(h)* could be calculated as follows [3]:

$$P(h) = a \cdot P_{\max} + (1-a) \cdot P_{\max} \cdot h \tag{1}$$

General value of a is 0.7, which means the idle power of a single server accounts for 70% of P_{max} . Thus total power of working servers in x-th interval can be obtained by (2):

$$P_{Servers,x} = M_x \cdot P(h_x) \tag{2}$$

2.2. CRACs power based on SQ model

We assume that all CRACs are identical, and the state of CRAC compressor is directly determined by the change of cold air duct temperature. Through the simplification of the equivalent thermal parameters model in [4], the SQ model [5] of a CRAC can be obtained, as is shown in (3)-(5).

$$T_i^{t+1} = T_i^t + \Delta t \cdot (T_+ - T_-) / \tau_0, \alpha = 0 \tag{3}$$

$$T_i^{t+1} = T_i^t - \Delta t \cdot (T_+ - T_-) / \tau_1, \alpha = 1 \tag{4}$$

$$\delta = T_+ - T_- \tag{5}$$

In (3) (4), τ_0 and τ_1 respectively denote the "off" and "on" time in a SQ cycle. As is shown in Figure.2., Its SQ cycle has 10 states that there are 5 distinct "on" states (blue) and 5 distinct "off" states (red), and at the end of each time step, CRAC units will move one state ahead.

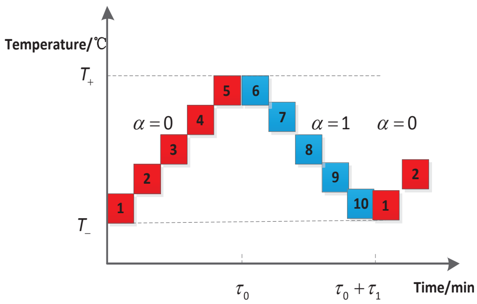

Figure.2. SQ model of a CRAC

The total CRACs load in x-th interval is simply the aggregated power output of total "on" units:

$$P_{CRACs,x} = N_x \cdot P_N \tag{6}$$

Therefore, we can calculate the total power load of datacenter according to (2) and (6):

$$L_{DC,x} = P_{Servers,x} + P_{CRACs,x} \tag{7}$$

3. Load control strategy

Datacenter workloads typically show a repetitive pattern with a period in the order of hours, days, weeks and so forth. In this paper, we use the product of average utilization *h* and number of working servers *M* to denote the workload *s* in a period, as is shown in (8).

$$s_x = h_x \cdot M_x \tag{8}$$

Before making load control strategy in a period, based on historical data about *h* and *M*, datacenter workloads can be predicted by the ARMA model [6].

$$s_x = (1-\alpha)\cdot s_{x-1} + \alpha \cdot \frac{1}{\beta}\sum_{m=1}^{\beta} s_{x,m} \tag{9}$$

Where α is used to denote the different weights of current value s_{x-1} and historical values $s_{x,m}$.

In this paper, our load control strategy consists of two submodules: server consolidation policy and temperature adjustment method of CRACs. According to workload prediction, we implement this piecewise control strategy to dynamically adjust number of working servers and temperature range of CRACs in different periods.

3.1. Server consolidation policy

Server consolidation refers to using the minimum number of active servers to make these severs achieving a perfect average utilization $h_{perfect}$, which could reduce the power consumption of datacenters without influencing workload completion.

According to workload prediction, the number of working servers required in x-th interval could be obtained from (10).

$$M_x = \lceil S_x / h_{perfect} \rceil \tag{10}$$

$$\Delta M_x = M_x - M_{x-1} \tag{11}$$

In (11), ΔM_x denotes the adjustment amount of servers in every internal, and ΔM_x servers need to be opened if $\Delta M_x \geq 0$ while $|\Delta M_x|$ servers should be powered off when $\Delta M_x < 0$.

3.2. Temperature adjustment method of CRACs

It's assumed that we will carry out our strategy in *m* intervals. Before determining temperature range in every interval, we firstly divide these *m* intervals into *w* groups, each group consists of *q* intervals, just as (12) shows.

$$\underbrace{s_{k,1}\cdots s_{k,q}}_{k=1},\underbrace{s_{k,1}\cdots s_{k,q}}_{k=2},\underbrace{s_{k,1}\cdots s_{k,q},\cdots,s_{k,1}\cdots s_{k,q}}_{k=3,\cdots\cdots,w-1},\underbrace{s_{k,1}\cdots s_{k,q}}_{k=w} \tag{12}$$

Then we sort q intervals of each group by predicted workload from high to low, select the maximum $s_{k,\max}$ and the minimum $s_{k,\min}$ in each group respectively. Through (1) (2) (10), we calculate the maximum and minimum power of servers $P_{servers,k,\max}$, $P_{servers,k,\min}$ in each group. We expect that the peak-load of each group could be reduced without creating new peak-load. Thus we dynamically determine the temperature range adjustment of all CRACs according to $P_{servers,k,\max}$ and $P_{servers,k,\min}$ in each interval, as is shown in (13)-(16).

$$\Delta T_{+,k} = \left\lfloor \frac{P_{servers,k,\max} - P_{servers,k,\min}}{2 \cdot P_N \cdot \varepsilon} \cdot \gamma \right\rfloor \cdot \varepsilon \tag{13}$$

$$\Delta T_{+,k,j} = \begin{cases} -\Delta T_{+,k}, s_{k,j} = s_{k,\min} \\ 0, s_{k,\min} < s_{k,j} < s_{k,\max} \\ \Delta T_{+,k}, s_{k,j} = s_{k,\max} \end{cases} \tag{14}$$

$$T_{+,x} = \begin{cases} T_{+,x-1} + \Delta T_{+,x}, T_{+,x-1} + \Delta T_{+,x} \le T_{+}^{\max} \\ T_{+}^{\max}, T_{+,x-1} + \Delta T_{+,x} > T_{+}^{\max} \end{cases} \tag{15}$$

$$T_{-,x} = \begin{cases} T_{+,x} - \delta, T_{+,x} - \delta \ge T_{-}^{\min} \\ T_{-}^{\min}, T_{+,x} - \delta < T_{-}^{\min} \end{cases} \tag{16}$$

Where ε denotes the temperature deadband of one state, which is determined by CRACs' SQ model, and γ is used to denote the average temperature rising required for closing one CRAC unit. Besides, $T_{-}^{\min}$ denotes the boundary limit avoiding unreasonable low temperature setting while the critical high temperature setting of CRACs $T_{+}^{\max}$ is determined by perfect average utilization.

Obtaining new temperature range by above, we conduct temperature setting adjustment according to $\Delta T_{+,x}$ as follows.

$\Delta T_{+,x} < 0$: For the CRACs at "on" state before adjustment, run according to the temperature range $[T_{-,x}, T_{+,x-1}]$ firstly. After these "on" units turning into "off" state in order, the temperature range becomes $[T_{-,x}, T_{+,x}]$ in turn. For the CRACs at "off" state before adjustment, run according to the temperature range $[T_{-,x-1}, T_{+,x-1}]$ firstly. When these units turn into "on" state in order, the temperature range becomes $[T_{-,x}, T_{+,x-1}]$ in turn. Then these "on" CRACs turn into "off" state in order, the temperature range becomes $[T_{-,x}, T_{+,x}]$ in turn.

$\Delta T_{+,x} \ge 0$: For the CRACs at "off" state before adjustment, run according to the temperature range $[T_{-,x-1}, T_{+,x}]$ firstly. After these "off" units turning into "on" state in order, the temperature range becomes $[T_{-,x}, T_{+,x}]$ in turn. For the units at "on" state before adjustment, run according to the temperature range $[T_{-,x-1}, T_{+,x-1}]$ firstly. When these units turn into "off" state in order, the temperature range becomes $[T_{-,x-1}, T_{+,x}]$ in turn. Then when these units turn into "on" state in order, the temperature range becomes $[T_{-,x}, T_{+,x}]$ in turn.

Thus the temperature range resetting is completed.

4. Example validation

4.1. Parameters setting

We use a datacenter with 20000 servers and 100 CRACs as example. The parameter setting is shown in Table 1.

Table 1. Parameter setting

Parameters	Value	Parameters	Value
P_{max}	0.2 kW	M_0	20000
Δt	1 min	$h_{perfect}$	80%
τ_0	5 min	m	12
τ_1	5 min	w	4
δ	1℃	q	3
$[T_{-,0},T_{+,0}]$	[19℃, 20℃]	$T_{+}^{\max}$	21℃
P_N	10 kW	$T_{-}^{\min}$	19℃

In this paper, we use SQ model of CRACs shown in Figure.2 so that ε is 0.2℃, and set the length of a controllable interval as 10min for simultaneous control. Initially, we assume that 100 CRACs are uniformly distributed among all 10 states so that there will always 50 CRAC units being “on” state if there is no artificial temperature adjustment.

Figure.3 shows the change of CRAC number in different state when $\Delta T_{+,x} = 0.4$, where white denotes “off” state and blue denotes “on” state. As is shown in Figure.3, number of “on” CRACs could be reduced to 30 from 50 so that $\gamma = 0.4/20 = 0.02$ ℃.

time	number-state of CRACs										N
0	10-1	10-2	10-3	10-4	10-5	10-6	10-7	10-8	10-9	10-10	50
1	10-2	10-1’	10-2’	10-3’	10-4’	10-7	10-8	10-9	10-10	10-1	40
2	10-1’	10-2’	10-3’	10-4’	10-5’	10-8	10-9	10-10	10-1	10-2	30
3	10-2’	10-3’	10-4’	10-5’	10-6’	10-9	10-10	10-1	10-2	10-1’	30
4	10-3’	10-4’	10-5’	10-6’	10-7’	10-10	10-1	10-2	10-1’	10-2’	30
5	10-4’	10-5’	10-6’	10-7’	10-8’	10-1	10-2	10-1’	10-2’	10-3’	30
6	10-5’	10-6’	10-7’	10-8’	10-9’	10-2	10-1’	10-2’	10-3’	10-4’	40
7	10-6’	10-7’	10-8’	10-9’	10-10’	10-1’	10-2’	10-3’	10-4’	10-5’	50
8	10-7’	10-8’	10-9’	10-10’	10-1’	10-2’	10-3’	10-4’	10-5’	10-6’	50
9	10-8’	10-9’	10-10’	10-1’	10-2’	10-3’	10-4’	10-5’	10-6’	10-7’	50
10	10-9’	10-10’	10-1’	10-2’	10-3’	10-4’	10-5’	10-6’	10-7’	10-8’	50

Figure.3. change of CRACs number in different state when $\Delta T_{+,x} = 0.4$

4.2. Simulation results

we assume that 5000,6000,4000,7000,6000,5000,8000,4000,6000,5000,7000,4000 are the predicted workloads by (8)-(9) in 12 intervals, then we implement our control strategy to validate its performance.

Figure.4 shows the comparison of total power load in different cases, it’s clear that the server consolidation policy could enormously reduce total power consumption of datacenter by comparing with uncontrolled case, and temperature range adjustment method of CRACs could contribute to peak-load shaving to some extent, which is conductive to reducing the burden of urban grid. Besides, Comparisons about high-temperature setting and number of working servers could be observed in Figure.5,6.

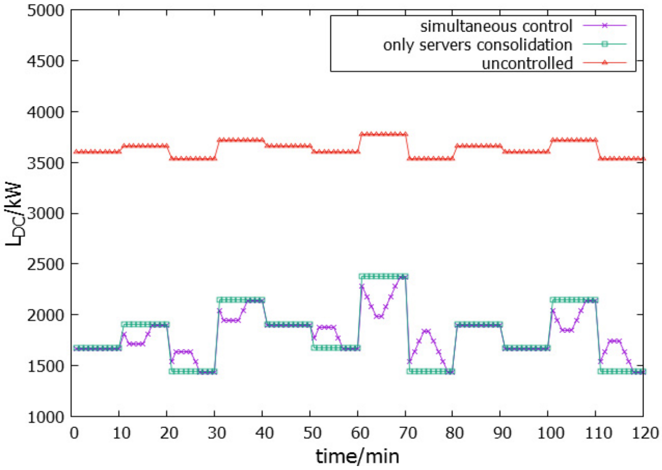

Figure.4. comparison of total power load

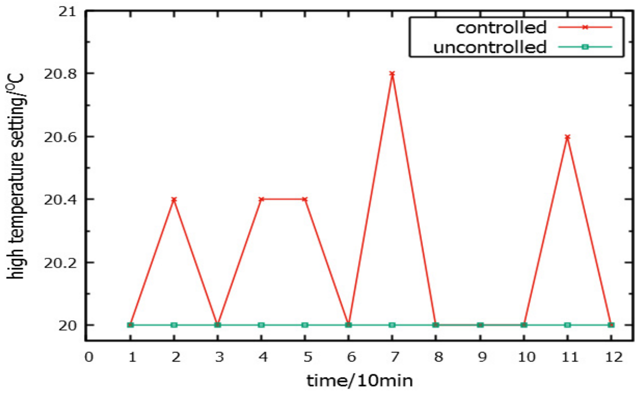

Figure.5. comparison of high-temperature setting

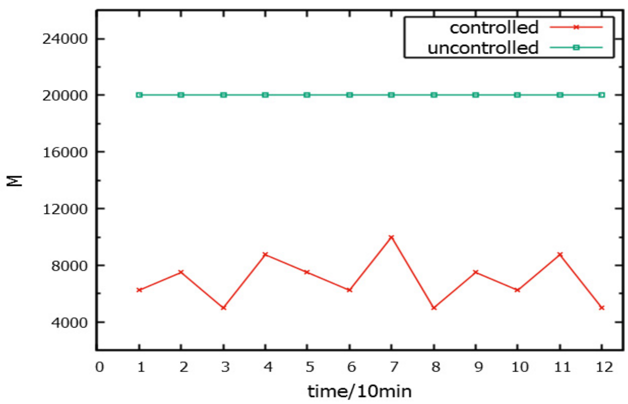

Figure.6. comparison about number of working servers

5. Conclusion

This paper proposes a simplified piecewise load control strategy of datacenters, which could dynamically adjust the number of working servers and temperature range of CRACs according to workload prediction in different periods. Not only it can enormously reduce total power consumption of datacenters, but also be conductive to achieving peak-load shaving. However, it may cause some load fluctuation as is shown in Figure.4 so that we will introduce energy storage technique, real-time electricity and so on in follow-up research to reduce the energy consumption of datacenters and the peak-load burden of urban grid by a comprehensive way.

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References

[1] Tang Q, Gupta S K S, Varsamopoulos G. Energy-efficient thermal-aware task scheduling for homogeneous high-performance computing data centers: A cyber-physical approach. *IEEE Transactions on Parallel & Distributed Systems* 2008; **19**: 1458-1472.

[2] Pakbaznia E, Ghasemazar M, Pedram M. Temperature-aware dynamic resource provisioning in a power-optimized datacenter. *Design, Automation & Test in Europe* Confer*ence & Exhibition* 2010; 124-129.

[3] Dong J, Wang H, Li Y, Chen S. Virtual Machine Scheduling for Improving Energy Efficiency in laaS Cloud. *China Communications* 2014; **3**:1-12.

[4] Zhou L, Yang Li, Gao C. Improvement of Temperature Adjusting Method for Aggregated Air-conditioning Loads and Its Control Strategy. *Proceedings of the CSEE* 2014; **34**:5579-5589.

[5] Lu N, Chassin D P, Widergren S E. Modeling uncertainties in aggregated thermostatically controlled loads using a state queueing model. *IEEE Transactions on Power Systems* 2005; **20**: 725-733.

[6] Shumway R H, Stoffer D S. *Time series analysis and its applications*. Springer Science & Business Media; 2013.

Biography

Ting yang is currently a Professor at Tianjin University, China. Professor Yang is a member of International Society for Industry and Applied Mathematics (SIAM), and the chairman of two workshops of IEEE International Conference. Professor Yang's research effort is focused on energy management system, intelligent control and communication of data center.